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Noise and Emissions Tradeoffs in the Environmental Design Space

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Overview

The research sponsered under grant NNL05AA02H for the academic year 2006 is summarized within. Mr Paul Brett conducted the research under the academic advisement of Dr. Dimitri N. Mavris and NASA technical advisor Dr. Fayette Collier of the Systems Analysis Branch. Originally, Mr Benjamin Berry conducted research in the academic year 2005; however, his graduation prompted an end to his research and Mr Brett was brought in as a replacement student and is currently in his second year of research.

Research Summary

Motivation

Environmental issues have become a forefront issue in the aerospace industry due to increased political pressure and scientific research. Therefore, a growing need to understand the tradeoffs between noise, emissions, performance, and cost continues to make itself known. In 2010, the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) plan to consider these tradeoffs and will consider, for the first time, noise and emissions regulations simultaneously.

Additionally, the FAA has recognized this need and launched a program to develop the tools to enable addressing CAEP's needs. This toolset incorporates three aspects of the aviation community simultaneously: vehicles and engines, worldwide inventories and fleet operations, and both local and global economic impacts of regulations. These three tools are correspondingly named: the Environmental Design Space (EDS), the Aviation Environmental Design Tool (AEDT), and the Aviation Environmental Portfolio Management Tool (APMT). EDS is a collaboration effort with Georgia Tech, MIT, NASA, and the FAA.

EDS Toolset

EDS currently utilizes many integrated tools that have also been used in other NASA studies such as Vehicle Systems Program and Ultra Efficient Engine Technology. These tools include Numerical Propulsion System Simulation (NPSS), Weight Analysis of Turbine Engines

(WATE), FLight OPtimization System (FLOPS), and Aircraft NOise Prediction Program (ANOPP). Additionally, an emissions package from MIT has replaced the emissions package EINOX.

Research Focus

The main focus of this research has been the development of low speed aerodynamic prediction capability for usage within EDS. FLOPS contains a takeoff and landing module which provides the capability to produce flight trajectory profiles for ANOPP. Since noise is a function of trajectory and trajectory is a function of aerodynamics, the utilization of proper aerodynamics is key to properly predicting noise. Currently, FLOPS does not produce the takeoff and landing aerodynamics internally and are user defined instead. This means the profiles are only as good as the user defines them and is not a robust process.

In discussion with NASA and industry experts, efforts to predict low speed aerodynamics at a conceptual design level has often gone overlooked in place of capabilities such as Computational Fluid Dynamics (CFD). However, the CFD calculation process is far too lengthy to use for the conceptual design performed within EDS. Therefore, creating this capability would be a valuable gain to both EDS and FLOPS.

Initially, the objective was to perform literature searches to compile a list of aerodynamic coefficients for aircraft over the last fifty years. This method could be capable of calculating impact of technology on drag as historical data could be mapped over time to predict future capabilities. However given that airfoil design has become more proprietary and cross-sections deviate from the traditional NACA series designs, modeling aircraft drag based on similar airfoil-related coefficients becomes a challenge.

This same problem occurs with high lift surfaces; limited data exists to provide a sufficient historical projection and coefficients of surface deflection. Many sources laid out suggested guidelines or values to use; however, neither approach allows for projecting values to future vehicles. Therefore a geometry-based approach is needed to calculate the appropriate drag polar information for each aircraft.

MIT student Andrew March had done work towards developing a geometry-based approach to predict low speed aerodynamic data through collaboration with Boeing. This non-proprietary toolset provided a drag polar from a vortex lattice code, a skin friction code, and empirical corrections from papers found in the Engineering Sciences Data Unit. The advantage with this set of codes is that Boeing has assessed the results and validated them for certain Boeing aircraft: the 727, 737, 747, and 777. Unfortunately, this approach did not include angle of attack in regards to the polar and this fact makes integration with FLOPS much more difficult as the drag polar is also a function of angle of attack.

Given this difficulty, an approach was considered using legacy aerodynamic codes to calculate aerodynamic performance. A combination of Vehicle Sketch Pad (VSP), AERO2S, and BDAP were used to predict the aircraft aerodynamic performance. VSP produces a frame model of the aircraft that is input into the other two codes. BDAP predicts the skin friction drag from the wing, nacelles, and fuselage. AERO2S predicts lift-induced drag from the lifting surfaces. Results from this suite of codes can be found in the following section.

Preliminary Results and Discussion

The top priority for the toolset is validation of the results to confirm reasonableness. Unfortunately little data exists in public domain as previously mentioned, making validation more difficult. Given that the March code had been validated by Boeing, the results from this code were selected as the validation dataset. Results from the Boeing 777-200ER can be found below for the clean aircraft (no surface deflection), full takeoff flaps (15°), part takeoff flaps (5°), and landing (40°) in Figure 1.

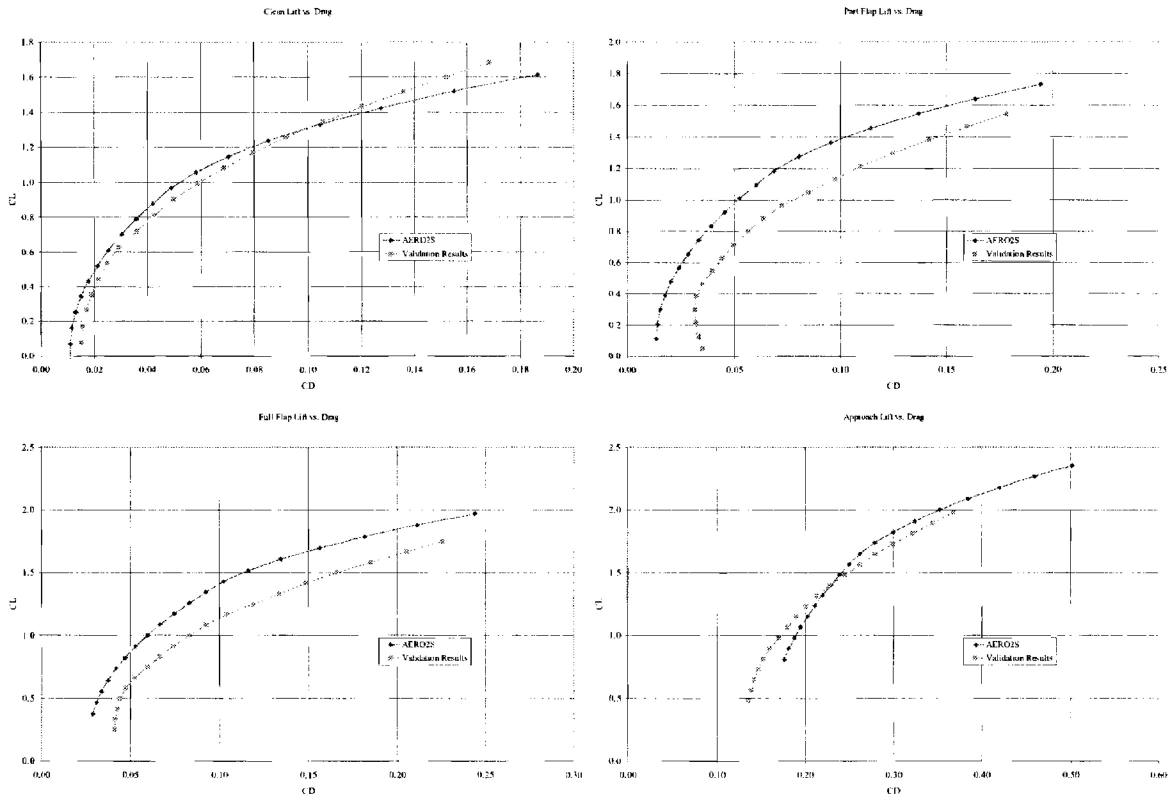

Figure 1. Validation of Predicted Polars.

Looking at the polars for takeoff and landing, the clean aircraft are almost identical in both trend shape and quantitatively. However as the error in the two polars increases with increased flap deflection, the inability of our suite to capture the flow separation that occurs when high lift devices are enabled begins to stand out. Although the trends are quite similar, the magnitudes are far different. Scalars could be applied to the predicted polars to match the validation data; however, this approach may not be repeatable for different vehicle classes. Minimal information was found in literature search with regards to empirical corrections that would help to more accurately predict the flow separation effects.

The current trade space around the 300 passenger aircraft involves a fixed airframe around a flexible engine cycle. Variations in engine size were run through this suite of codes and the change in drag came out as negligible. However for airframe major geometry changes, changes in lift and drag have the potential to be much more severe.

Future Work

Since this effort has been only one year for Mr Brett, future work exists regarding the low speed aerodynamics prediction capability. The MIT code that had initially been developed has now incorporated changes that make this code a feasible option with incorporation into the FLOPS takeoff and landing module. Surrogate modeling will likely be the approach utilized to incorporate the low speed prediction capability into FLOPS. This current year will be spent down-selecting inputs for the model, creating and validating an appropriate model, and incorporating the model into FLOPS and validating the results. As this capability was based around fixed Boeing aircraft, it will be interesting to see how accurately it will predict takeoff and landing performance for Airbus aircraft and additionally within the parametric aircraft spaces for EDS vehicles.

This grant has funded my efforts in getting a Masters Degree in Aerospace Engineering, to be earned this December. I will continue on my work on low speed aerodynamics in the following academic year as I prepare myself for taking PhD qualifiers in Fall 2008. Many thanks are given to my advisors Dr Mavris and Dr Collier for this research opportunity. Additional thanks are given to Dr Michelle Kirby for her support during my research.

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